# The Project 8 radiofrequency tritium neutrino experiment

**Ben Monreal, UCSB**
**for the Project 8 collaboration**

In Fig. 1, the end of the distribution curve for $\mu=0$ and for large and small values of $\mu$ is sketched. The greatest similarity to the empirical curves is given by the theoretical curve for $\mu=0$.

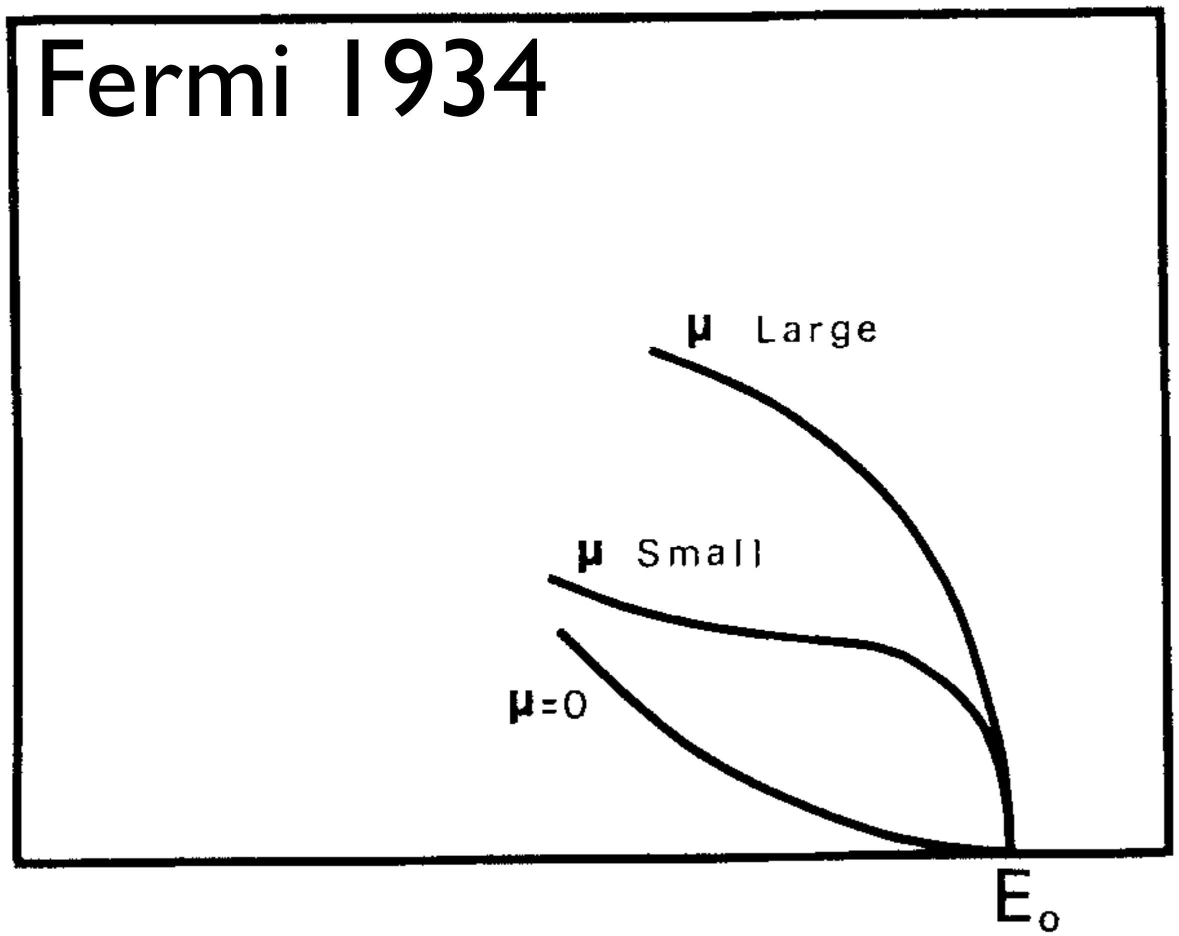
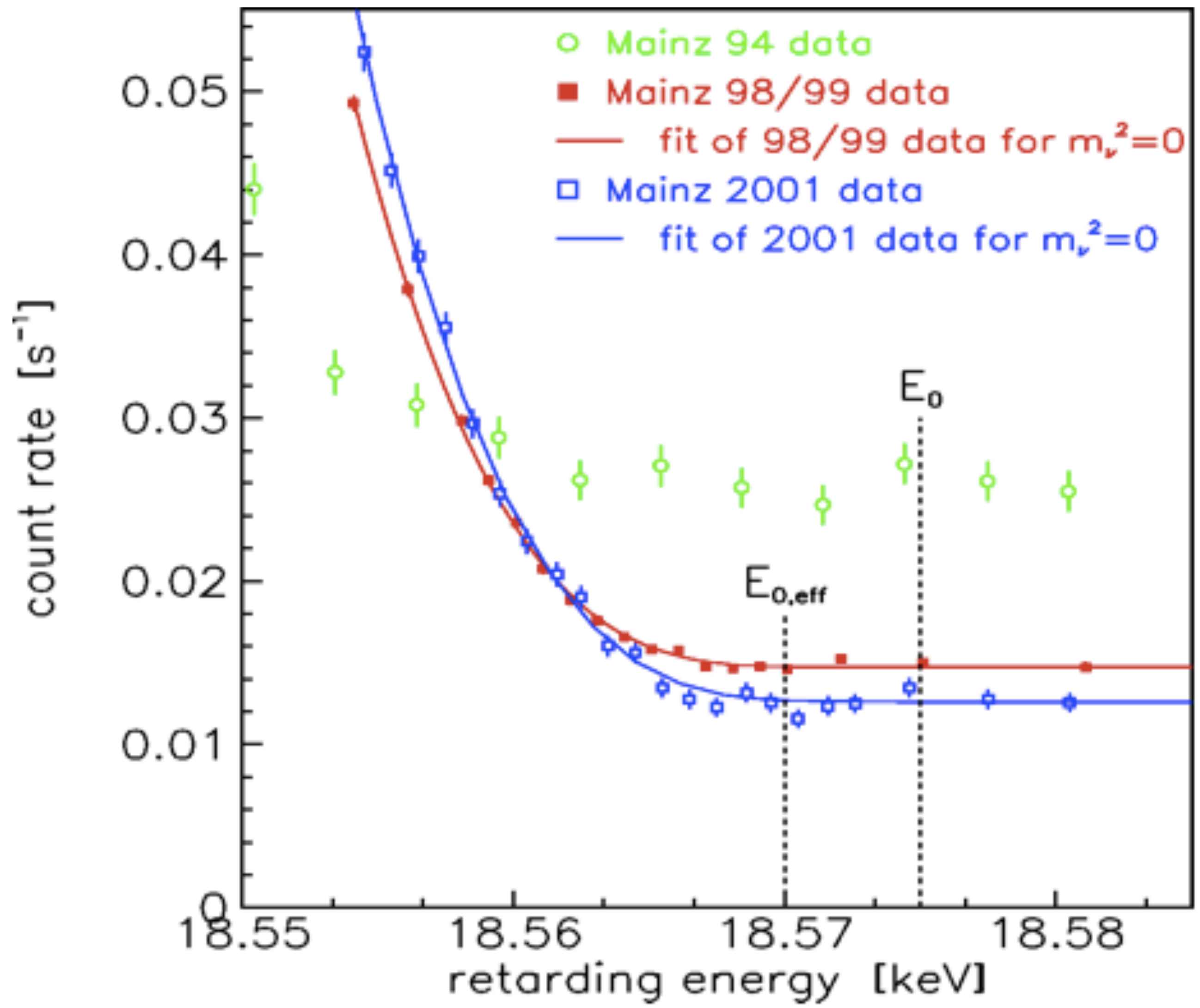



Fig. 1. The end of the distribution curve for $\mu=0$ and for large and small values of $\mu$.

Hence, we conclude that the rest mass of the neutrino is either zero, or, in any case, very small in comparison to the mass of the electron.[10] In the

# The beta spectrum endpoint has been under continuous study since 1934

## Mainz 2005




KATRIN 2016–(?)
Project 8 201?–
MARE, ECHO 20??–

# The Project 8 concept

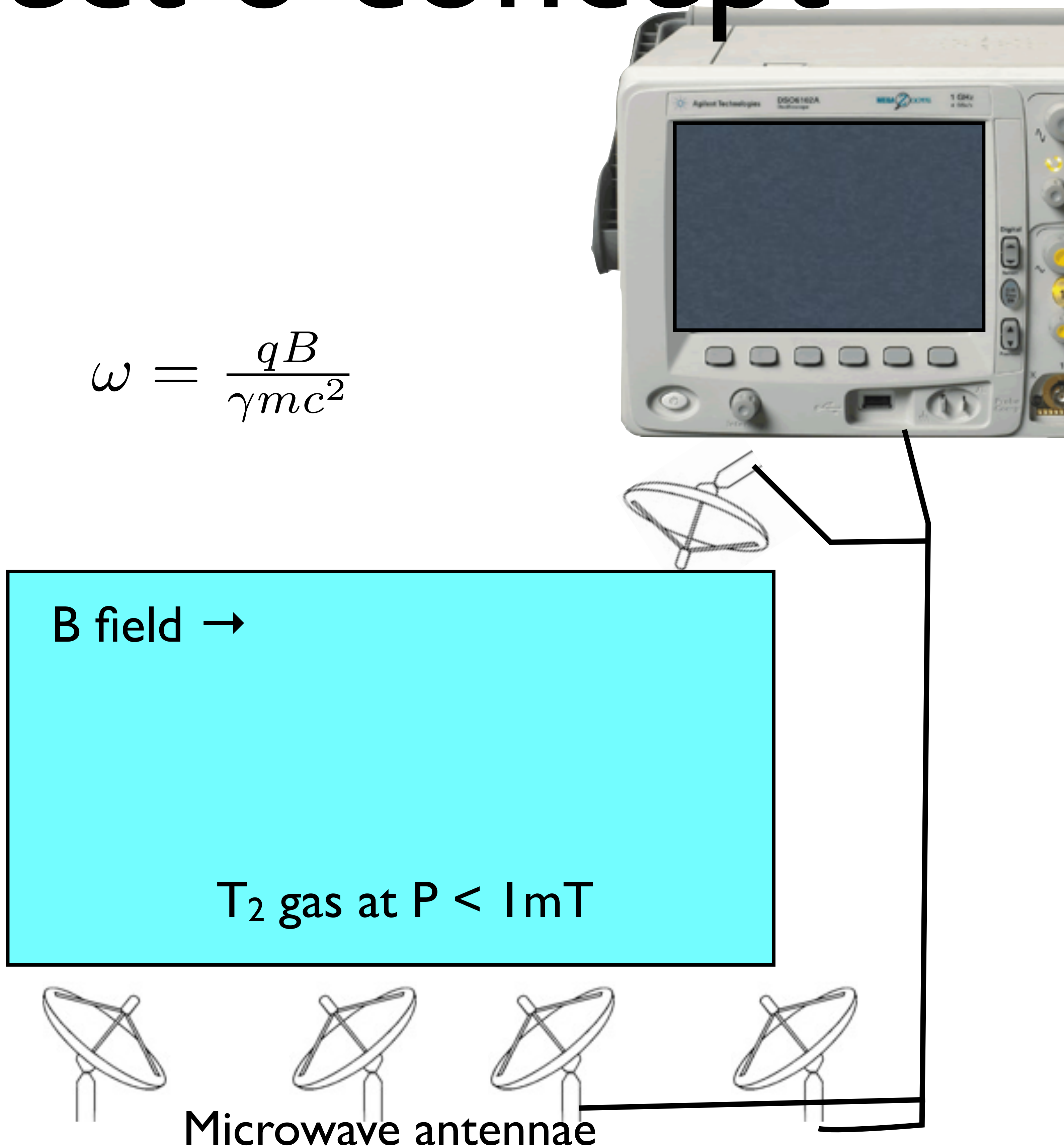
## Cyclotron radiation

- emitted by mildly relativistic electrons
- Coherent, narrowband
- $10^{-15}$ W per electron

$$P_{\text{tot}} = \frac{1}{4\pi\epsilon_0}\frac{2q^2\omega_c^2}{3c}\frac{\beta_\perp^2}{1-\beta^2}$$

- Electron energy contributes to velocity v, power P, frequency ω
  - *Can we detect this radiation, measure v, P, ω, and determine* E ± 1 eV?

$$\omega = \frac{qB}{\gamma m c^2}$$



# The Project 8 concept

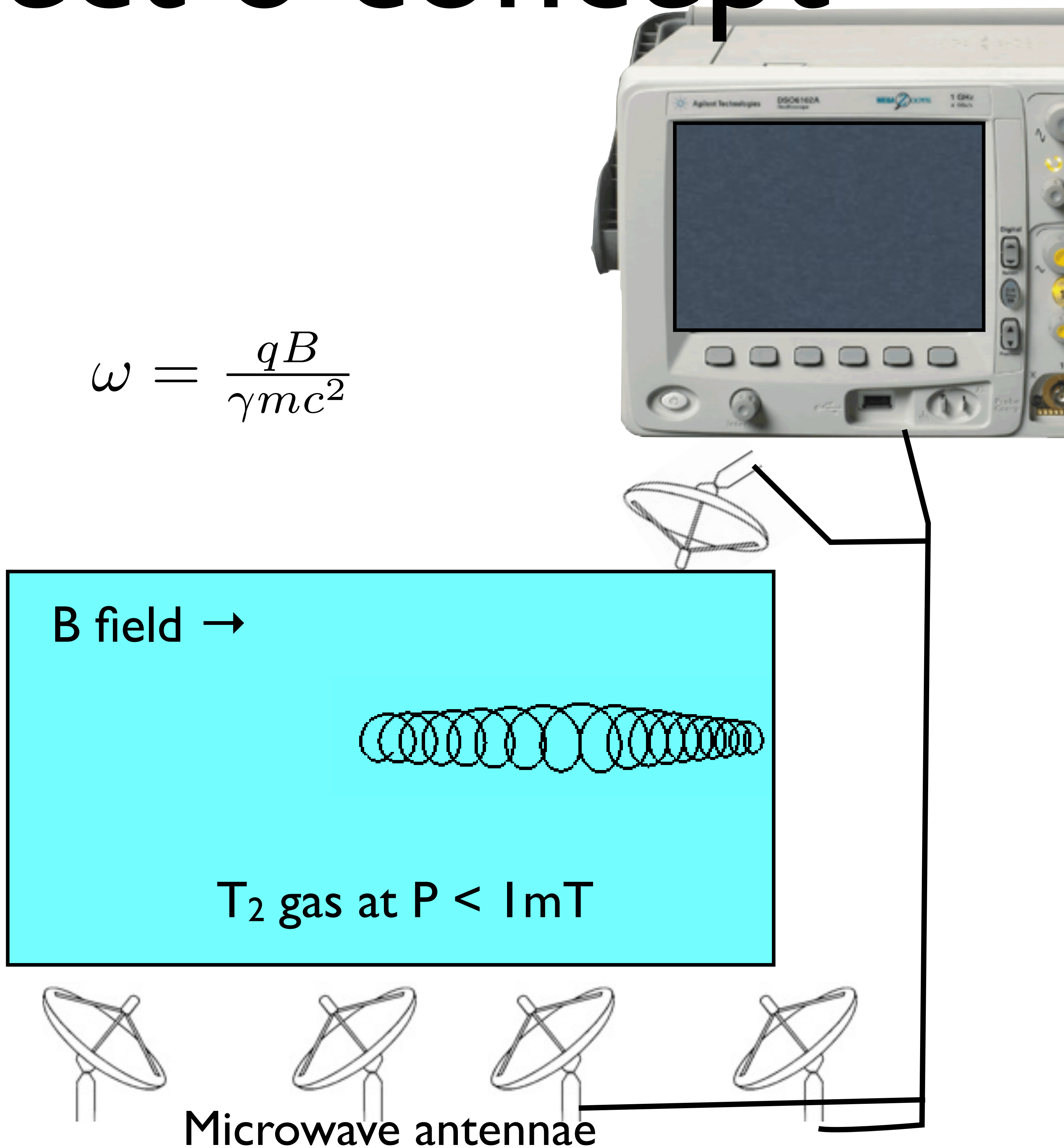
## Cyclotron radiation

- emitted by mildly relativistic electrons
- Coherent, narrowband
- $10^{-15}$ W per electron

$$P_{\text{tot}} = \frac{1}{4\pi\epsilon_0} \frac{2q^2\omega_c^2}{3c} \frac{\beta_\perp^2}{1-\beta^2}$$

- Electron energy contributes to velocity v, power P, frequency ω
  - *Can we detect this radiation, measure v, P, ω, and determine* E ± 1 eV?

$$\omega = \frac{qB}{\gamma m c^2}$$



# The Project 8 concept

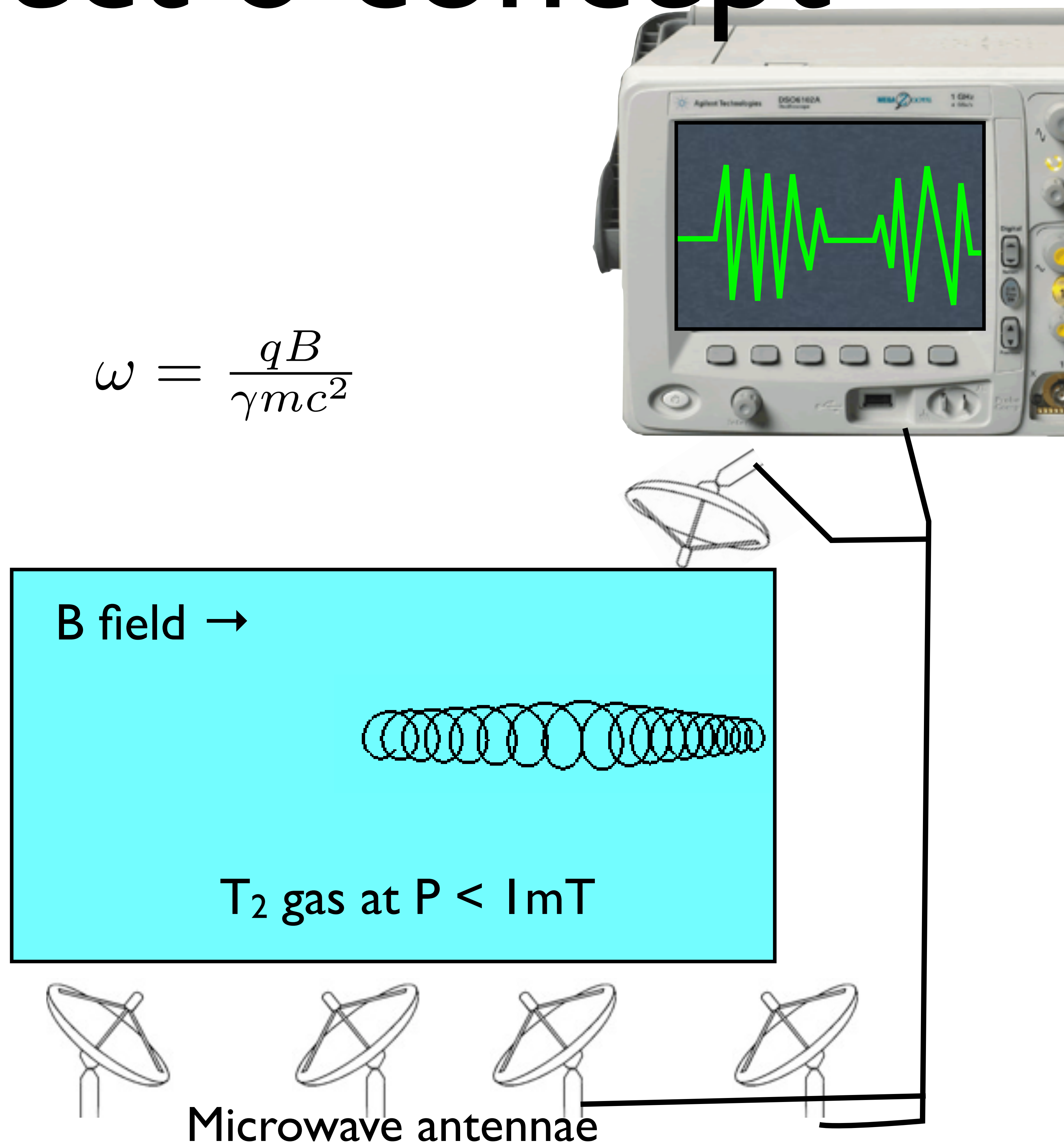
## Cyclotron radiation

- emitted by mildly relativistic electrons
- Coherent, narrowband
- $10^{-15}$ W per electron

$$P_{\text{tot}} = \frac{1}{4\pi\epsilon_0} \frac{2q^2\omega_c^2}{3c} \frac{\beta_\perp^2}{1-\beta^2}$$

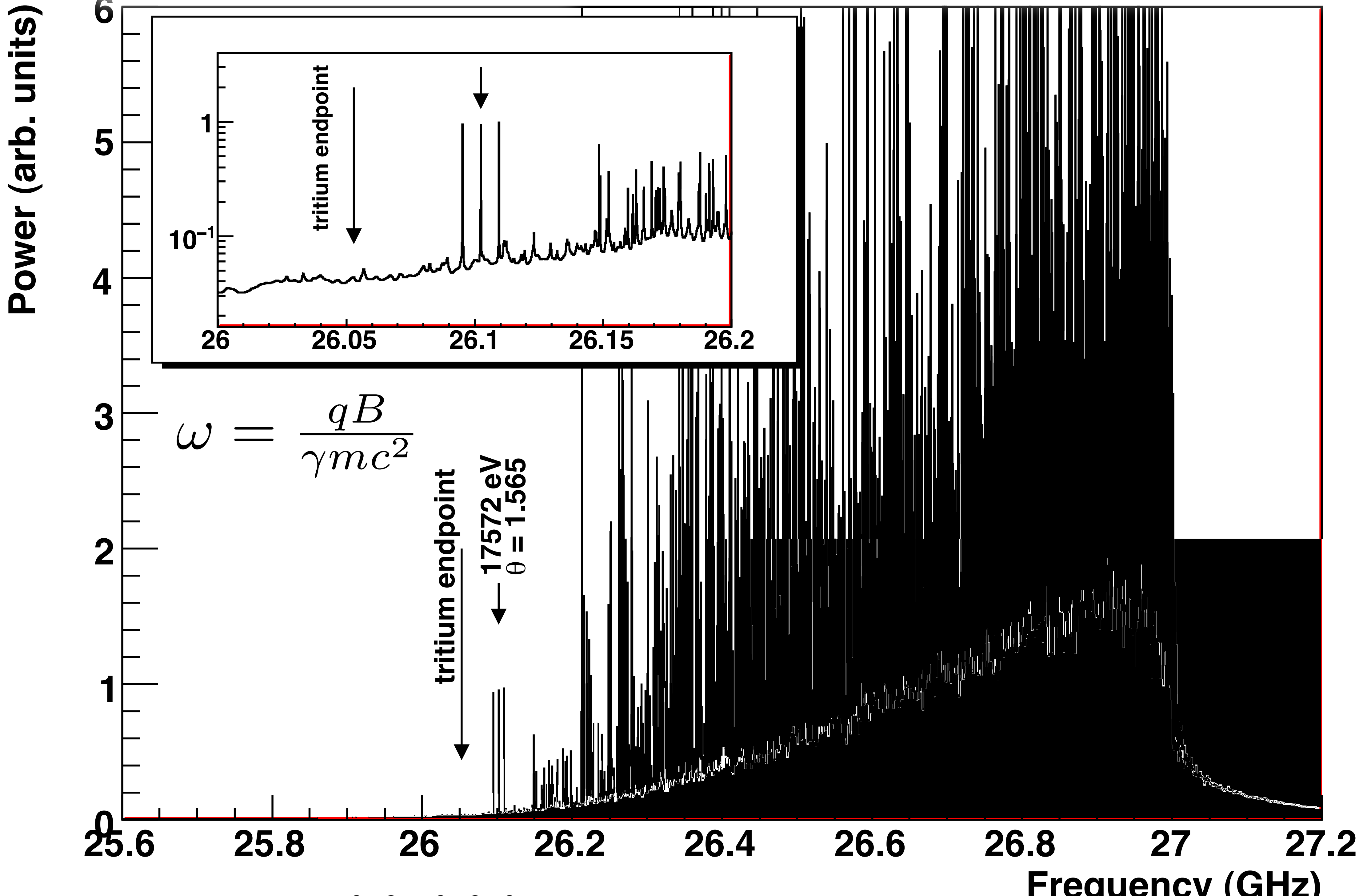
- Electron energy contributes to velocity v, power P, frequency ω
  - *Can we detect this radiation, measure v, P, ω, and determine* E ± 1 eV?

$$\omega = \frac{qB}{\gamma m c^2}$$



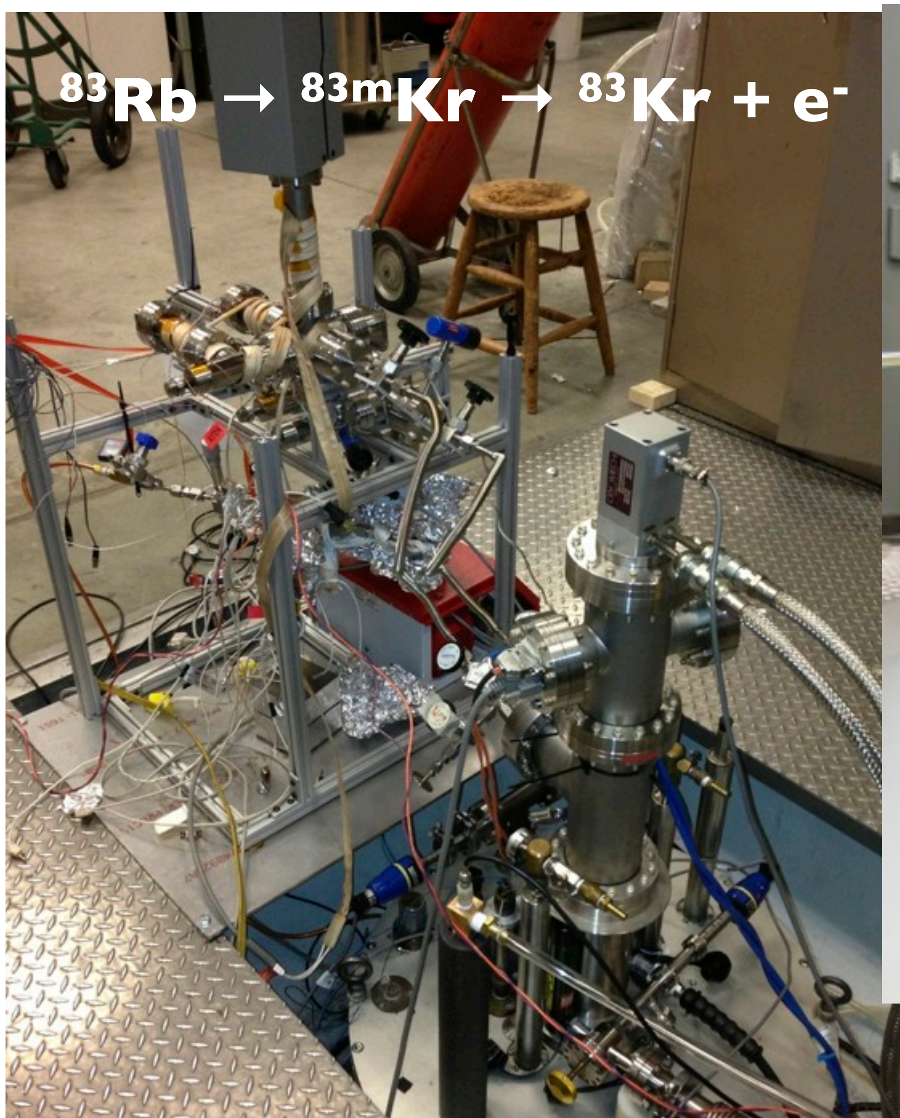
rare high-energy electrons

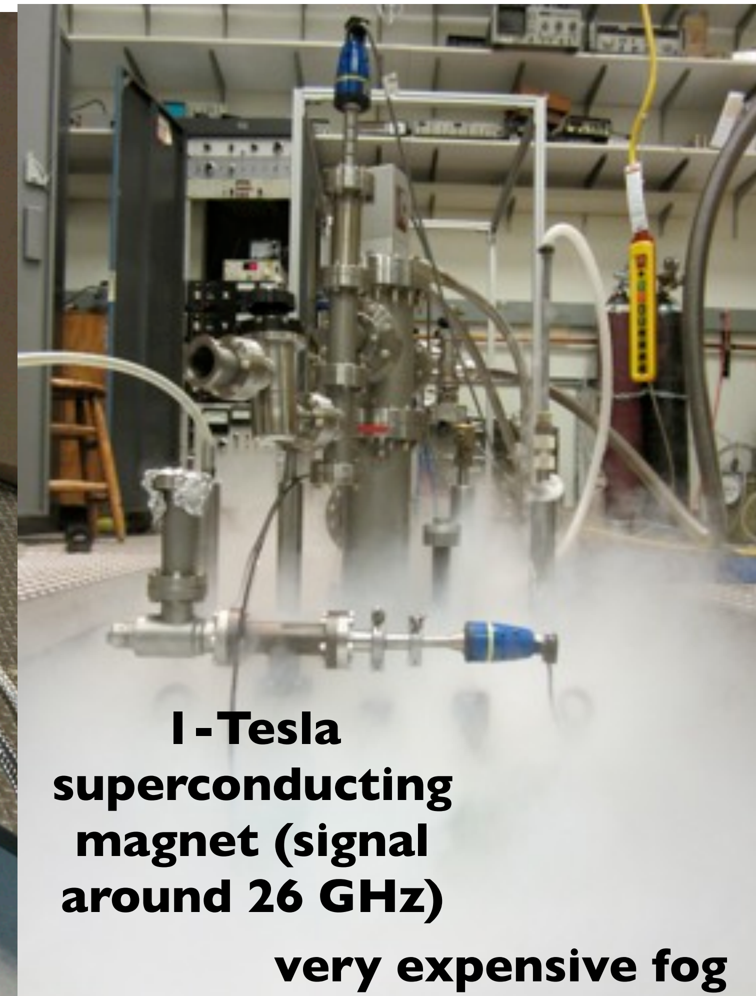
many overlapping low-energy electrons

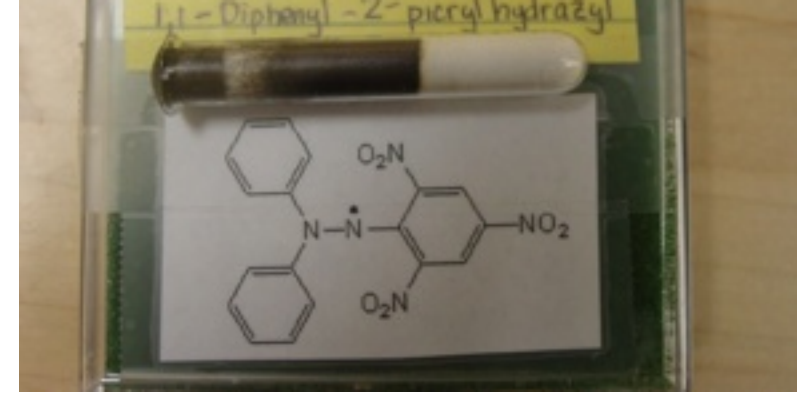



$$\omega = \frac{qB}{\gamma mc^2}$$

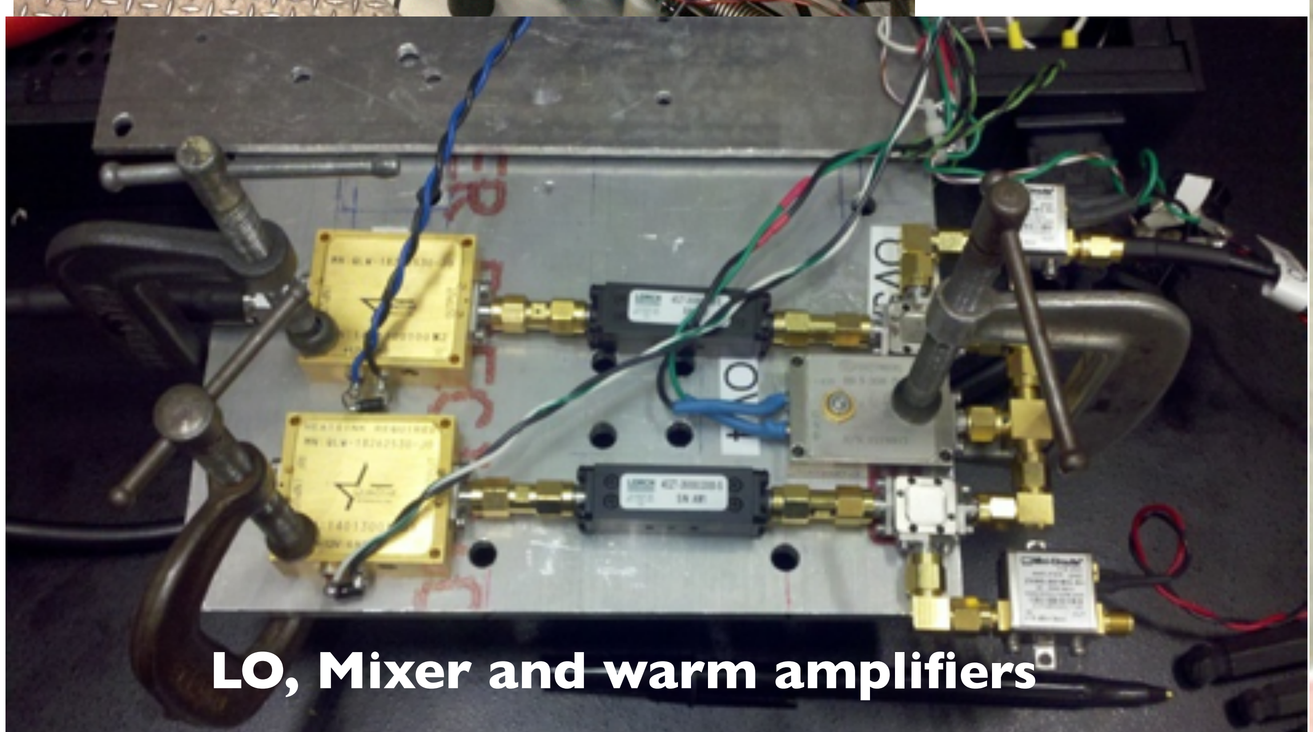
100,000 simulated $T_2$ decays

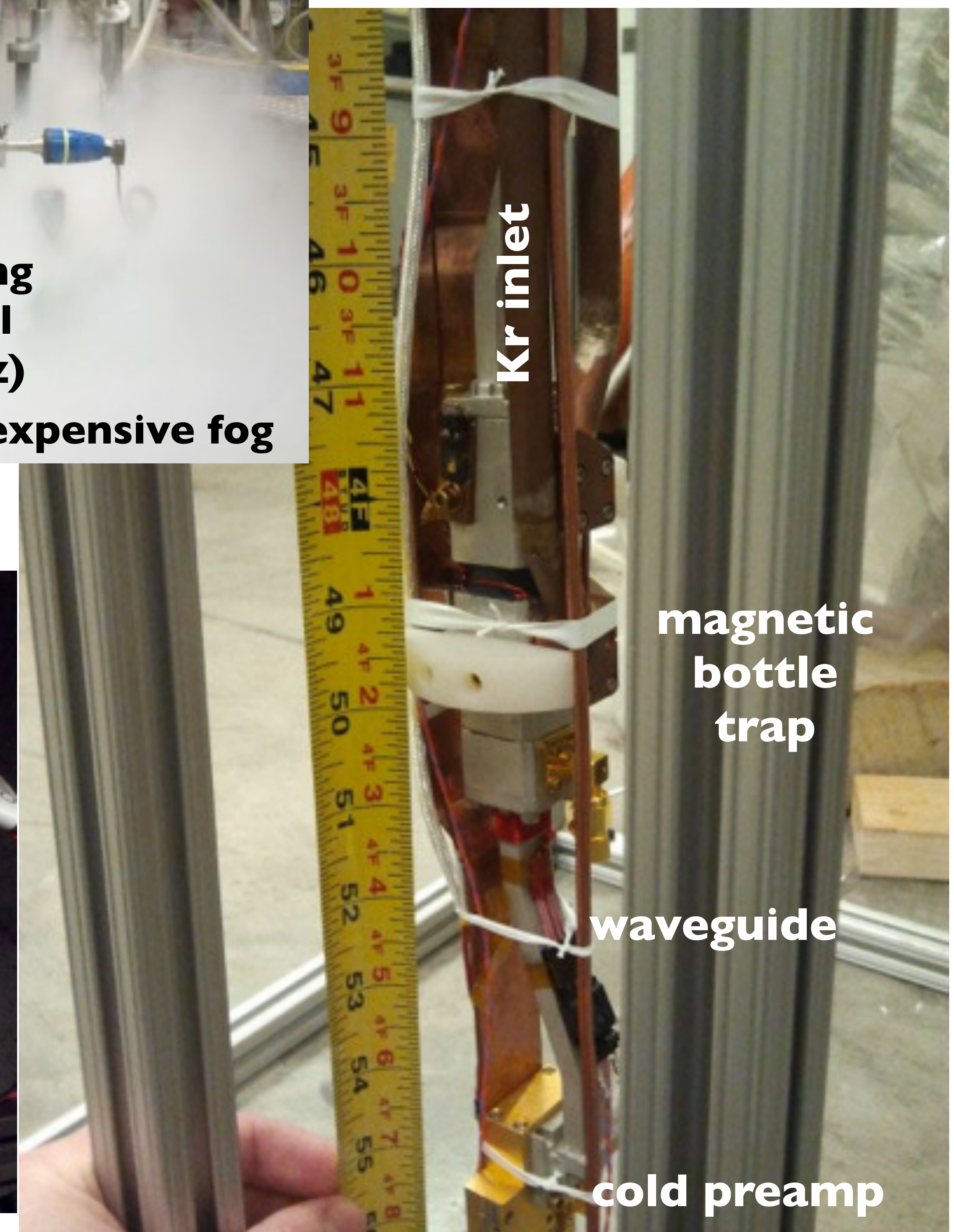


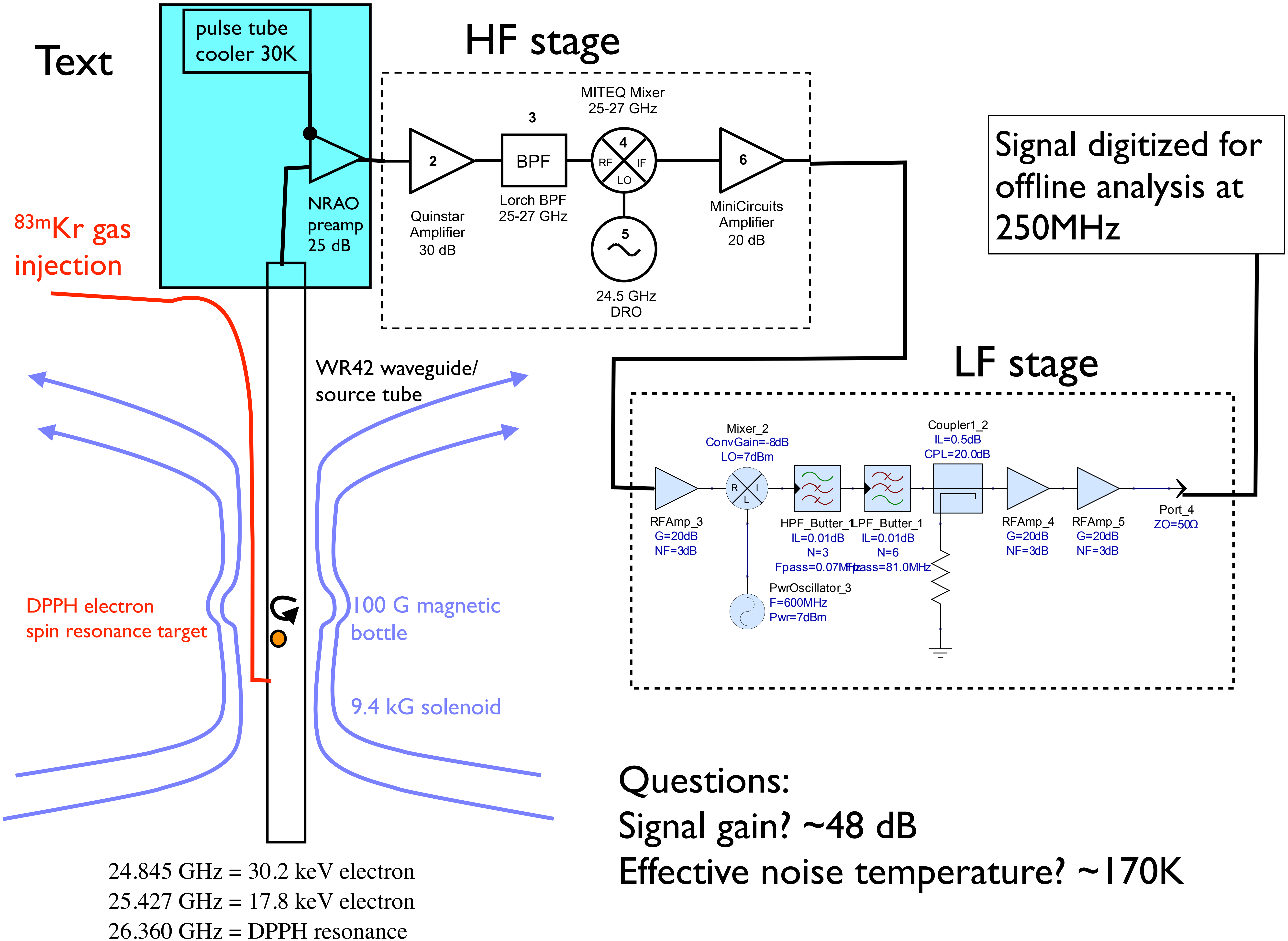



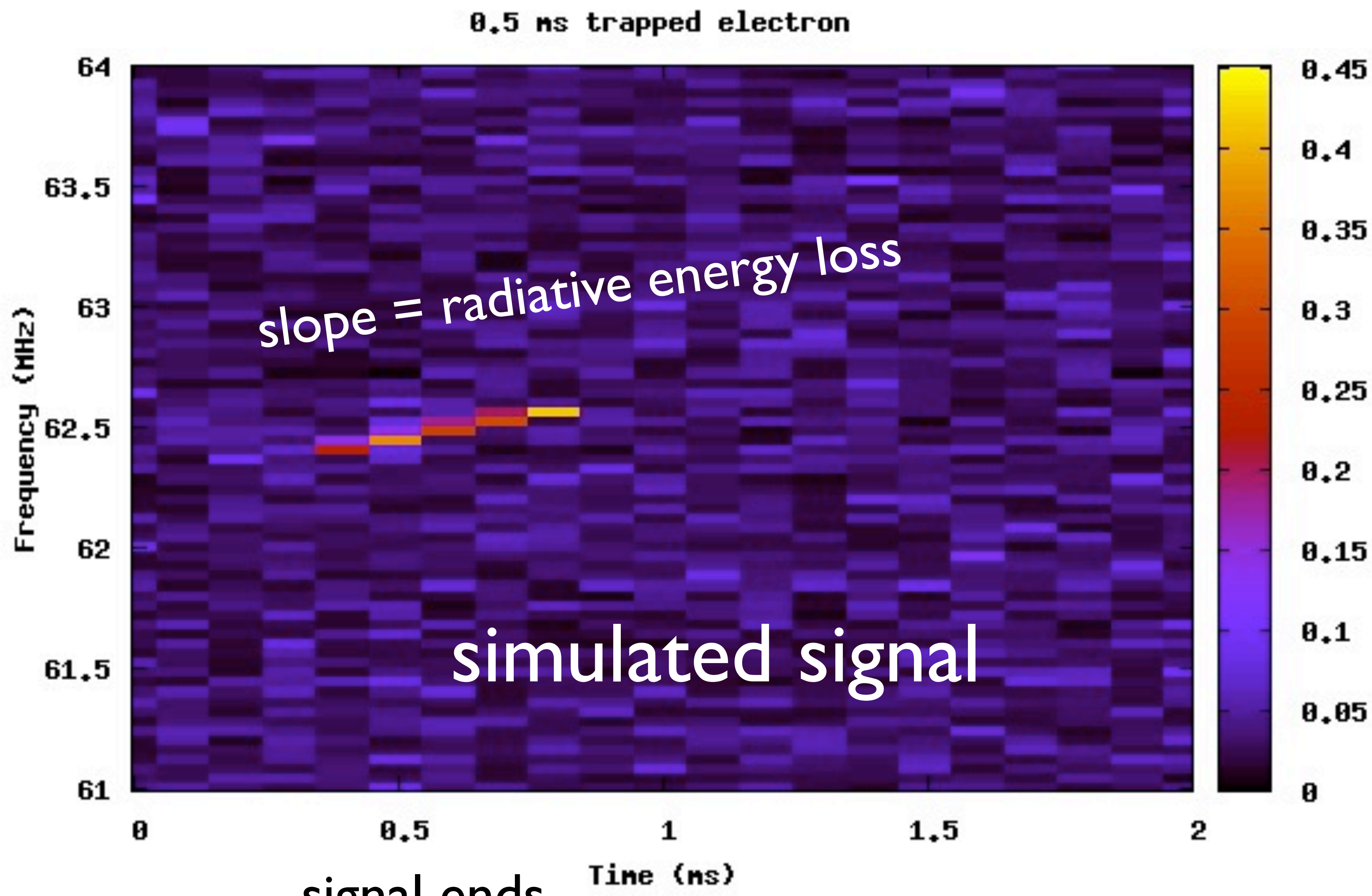

DPPH target (EPR microwave absorption) in waveguide



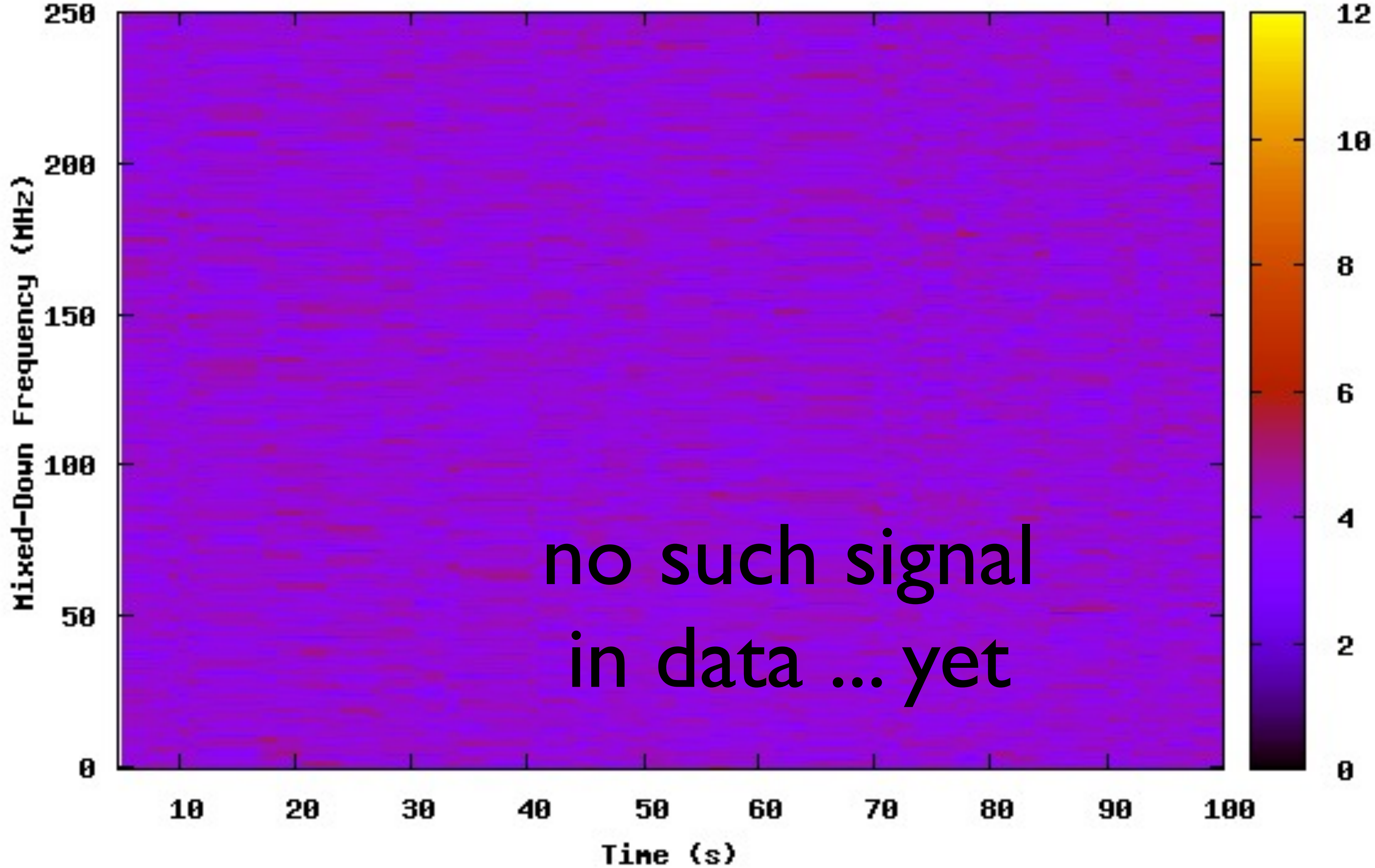

Text
pulse tube cooler 30K
NRAO preamp 25 dB
$^{83m}$Kr gas injection
HF stage
MITEQ Mixer 25-27 GHz
3
BPF
2
4
RF
IF
LO
5
6
Quinstar Amplifier 30 dB
Lorch BPF 25-27 GHz
24.5 GHz DRO
MiniCircuits Amplifier 20 dB
Signal digitized for offline analysis at 250MHz
WR42 waveguide/ source tube
LF stage
Mixer_2
ConvGain=-8dB
LO=7dBm
Coupler1_2
IL=0.5dB
CPL=20.0dB
R
I
L
RFAmp_3
G=20dB
NF=3dB
HPF_Butter_1
IL=0.01dB
N=3
Fpass=0.07MHz
LPF_Butter_1
IL=0.01dB
N=6
Fpass=81.0MHz
RFAmp_4
G=20dB
NF=3dB
RFAmp_5
G=20dB
NF=3dB
Port_4
ZO=50Ω
PwrOscillator_3
F=600MHz
Pwr=7dBm
DPPH electron spin resonance target
100 G magnetic bottle
9.4 kG solenoid
24.845 GHz = 30.2 keV electron
25.427 GHz = 17.8 keV electron
26.360 GHz = DPPH resonance
Questions:
Signal gain? ~48 dB
Effective noise temperature? ~170K

# 1 fW signal should be detectable over 90-100K background

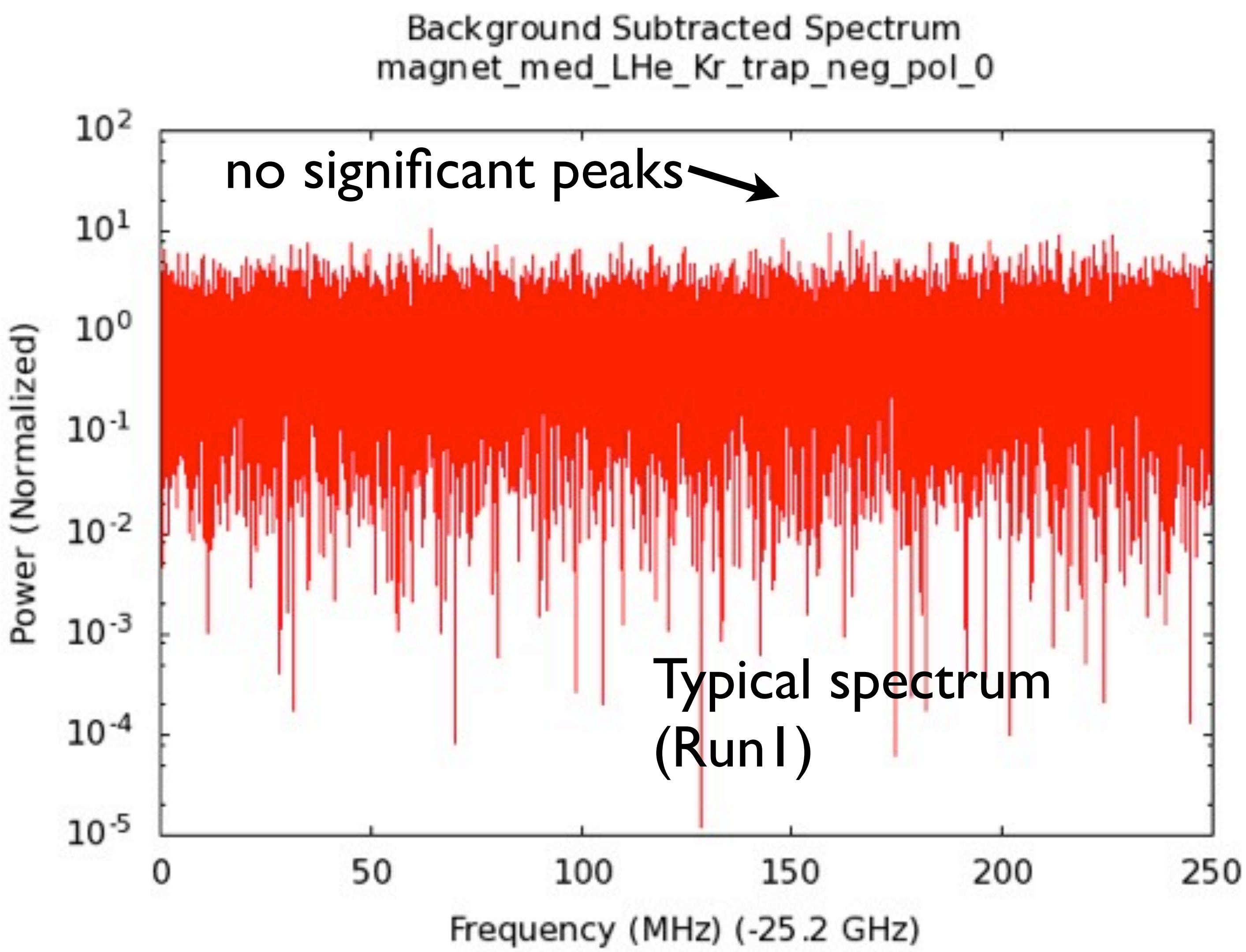


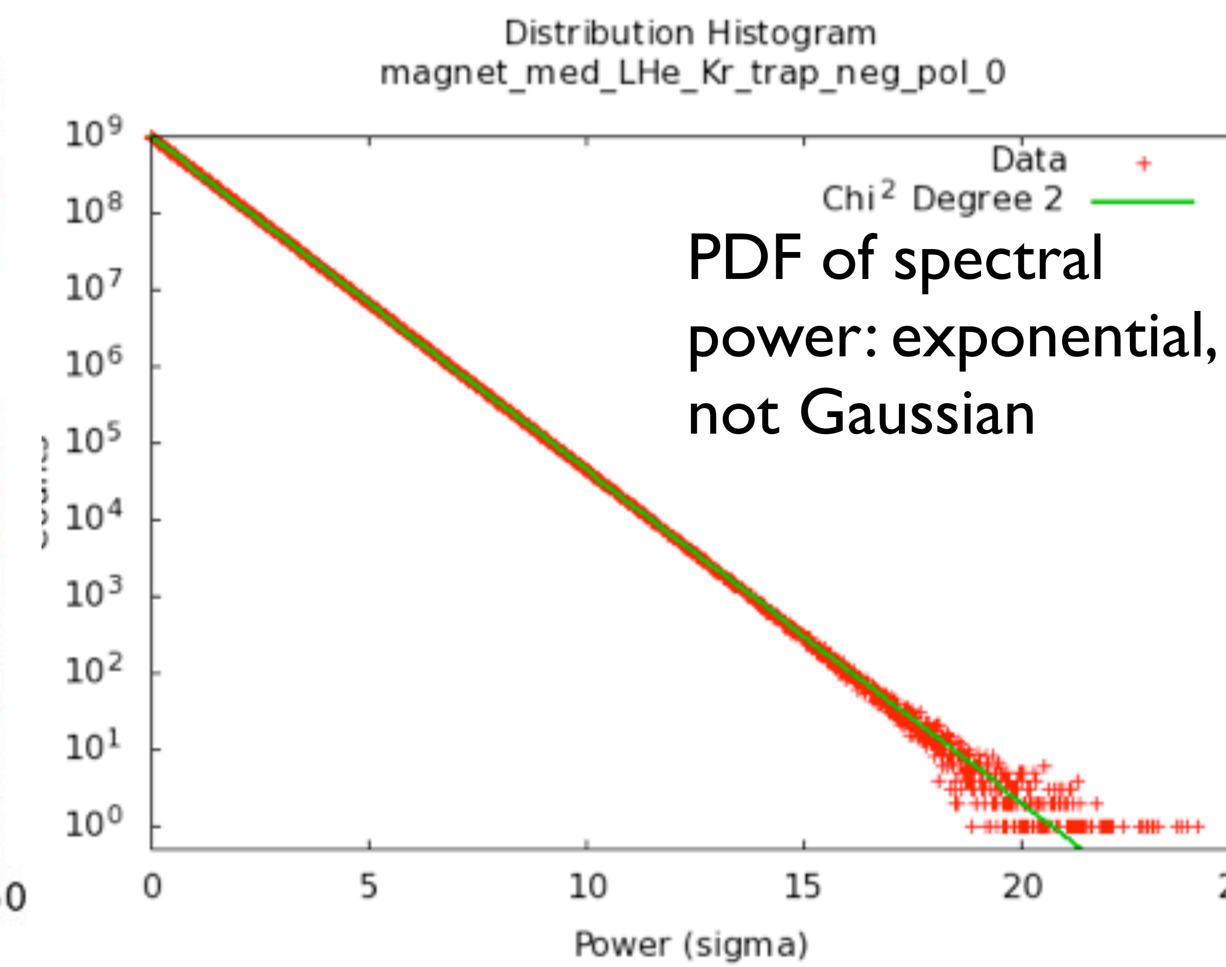

signal ends
after scatter
off residual gas

# First runs: thermal noise, no signal



# Early runs: lovely thermal noise

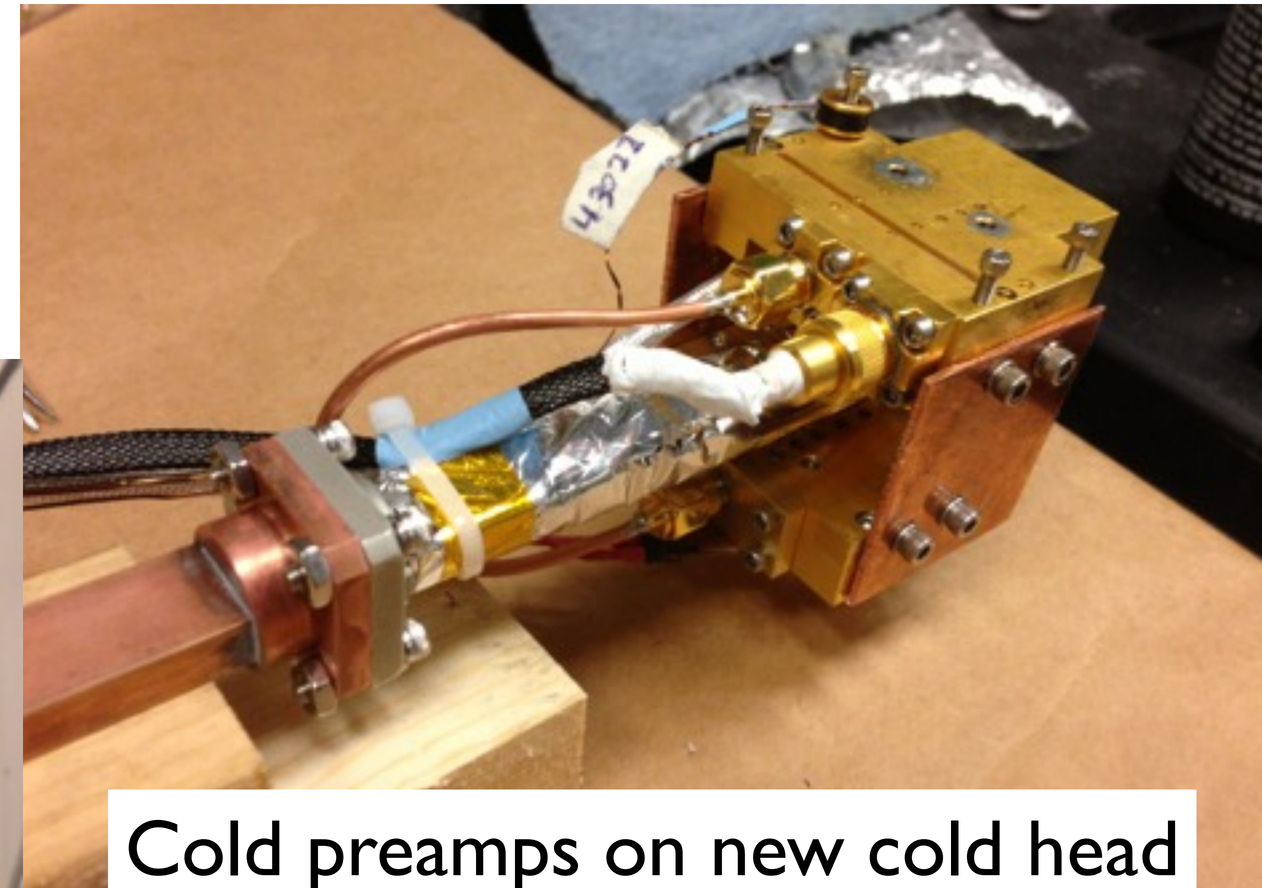


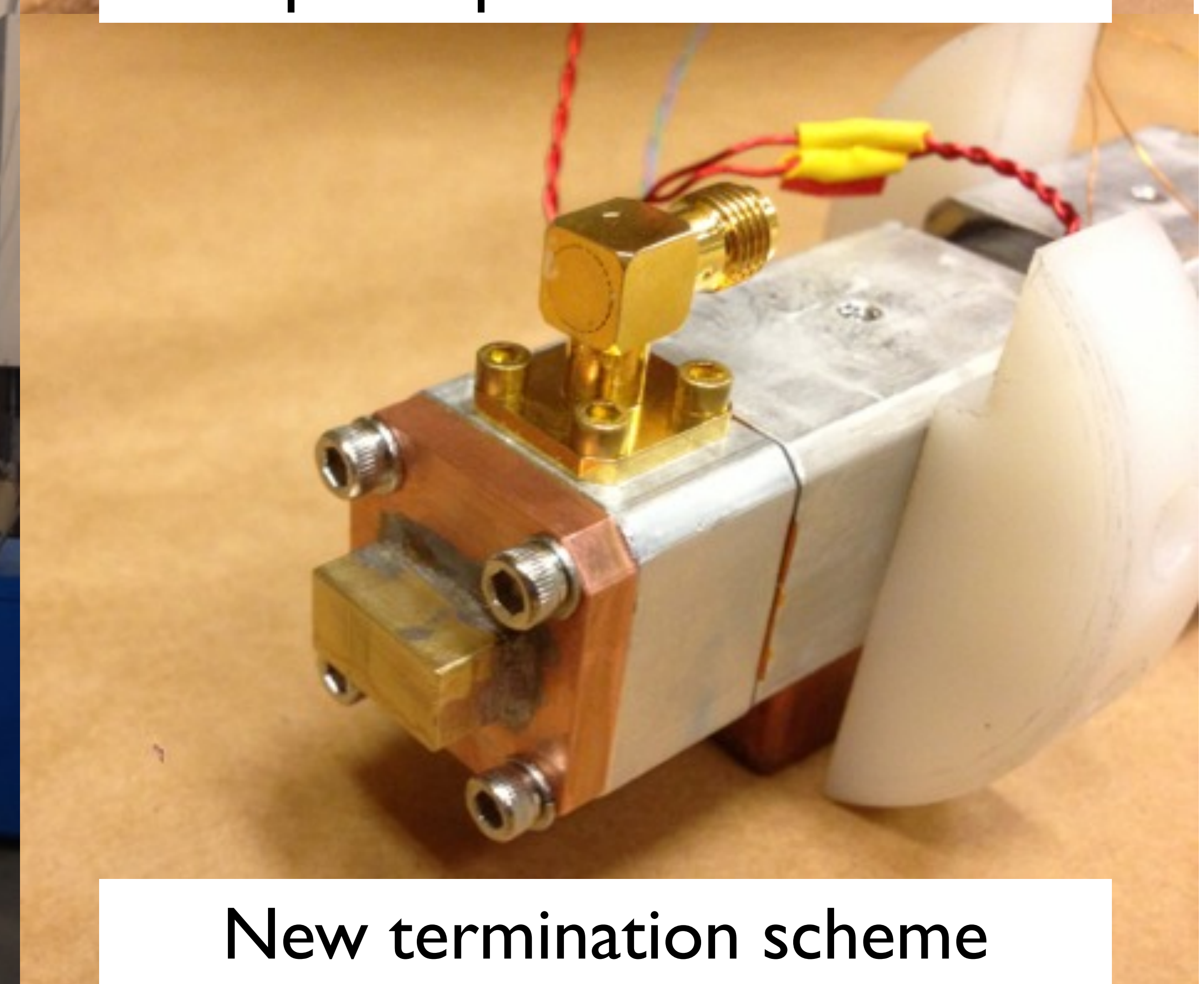




The "bins" in a power spectrum are NOT like bins in a histogram, and do NOT show Poisson statistics.
They're distributed like Gaussian random numbers *squared.*

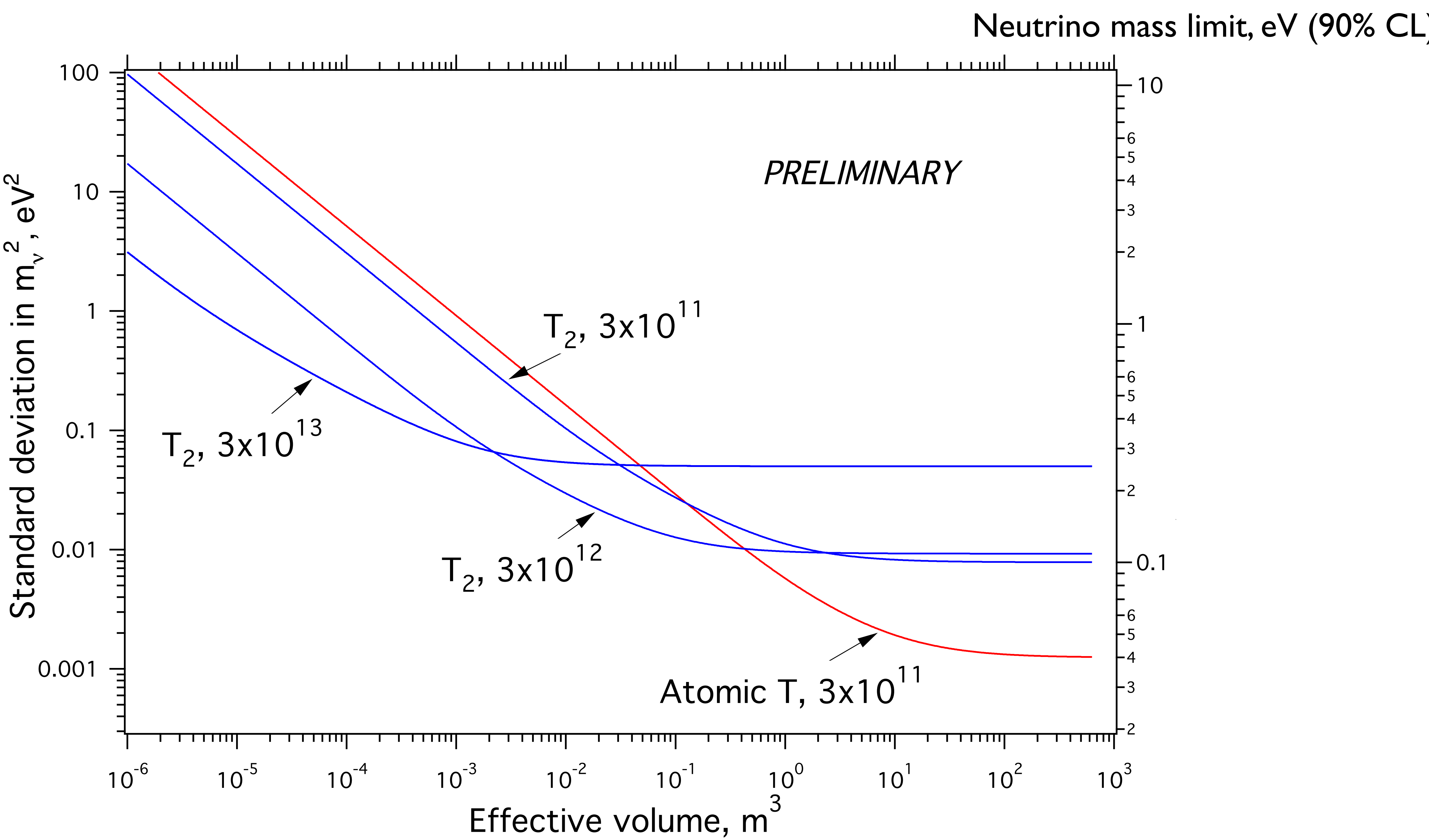
# UW prototype updates: More running this year!

New magnet! Warm-bore NMR from UCSB


Cold preamps on new cold head

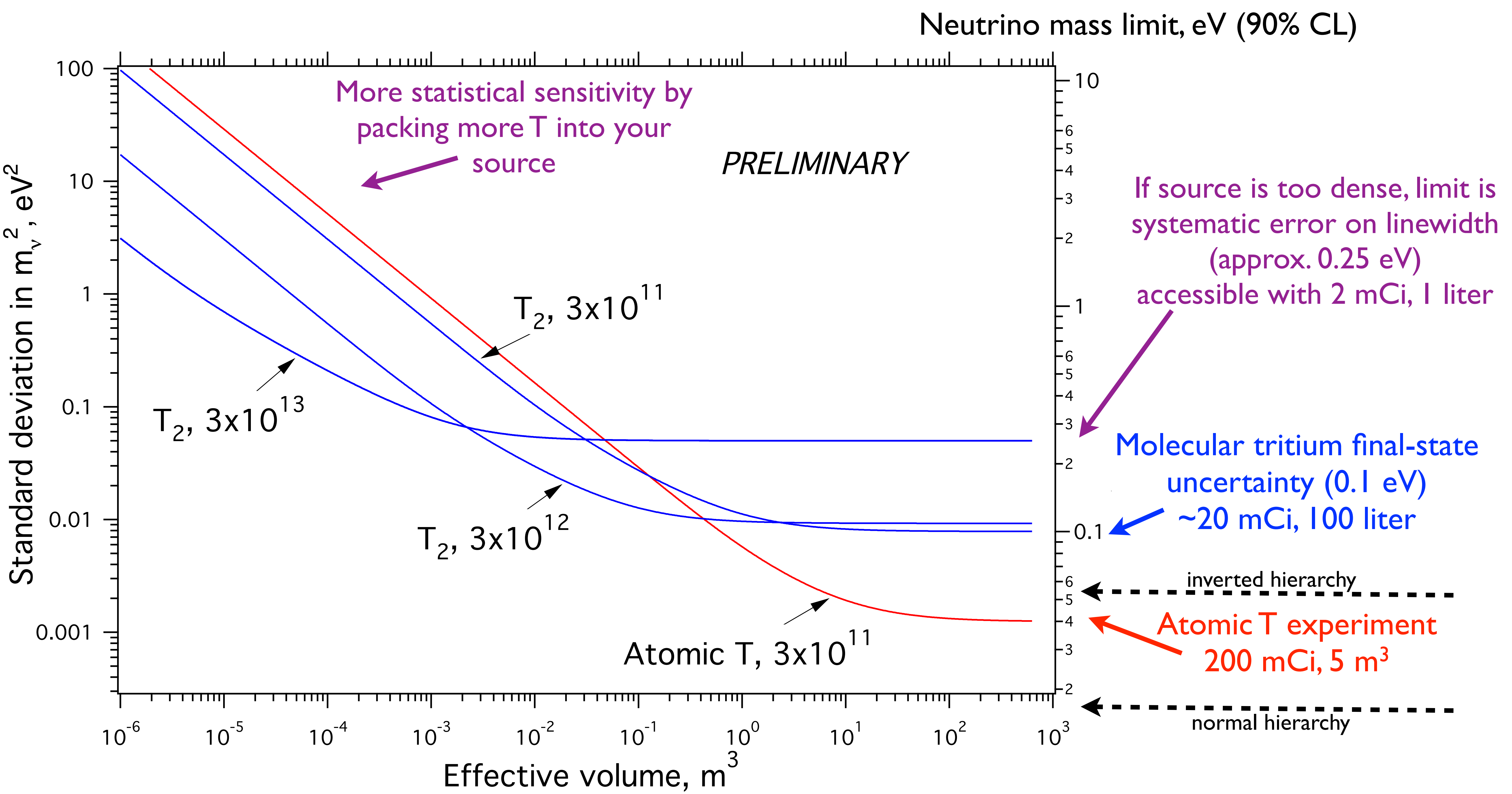

New termination scheme

# Recent sensitivity estimates



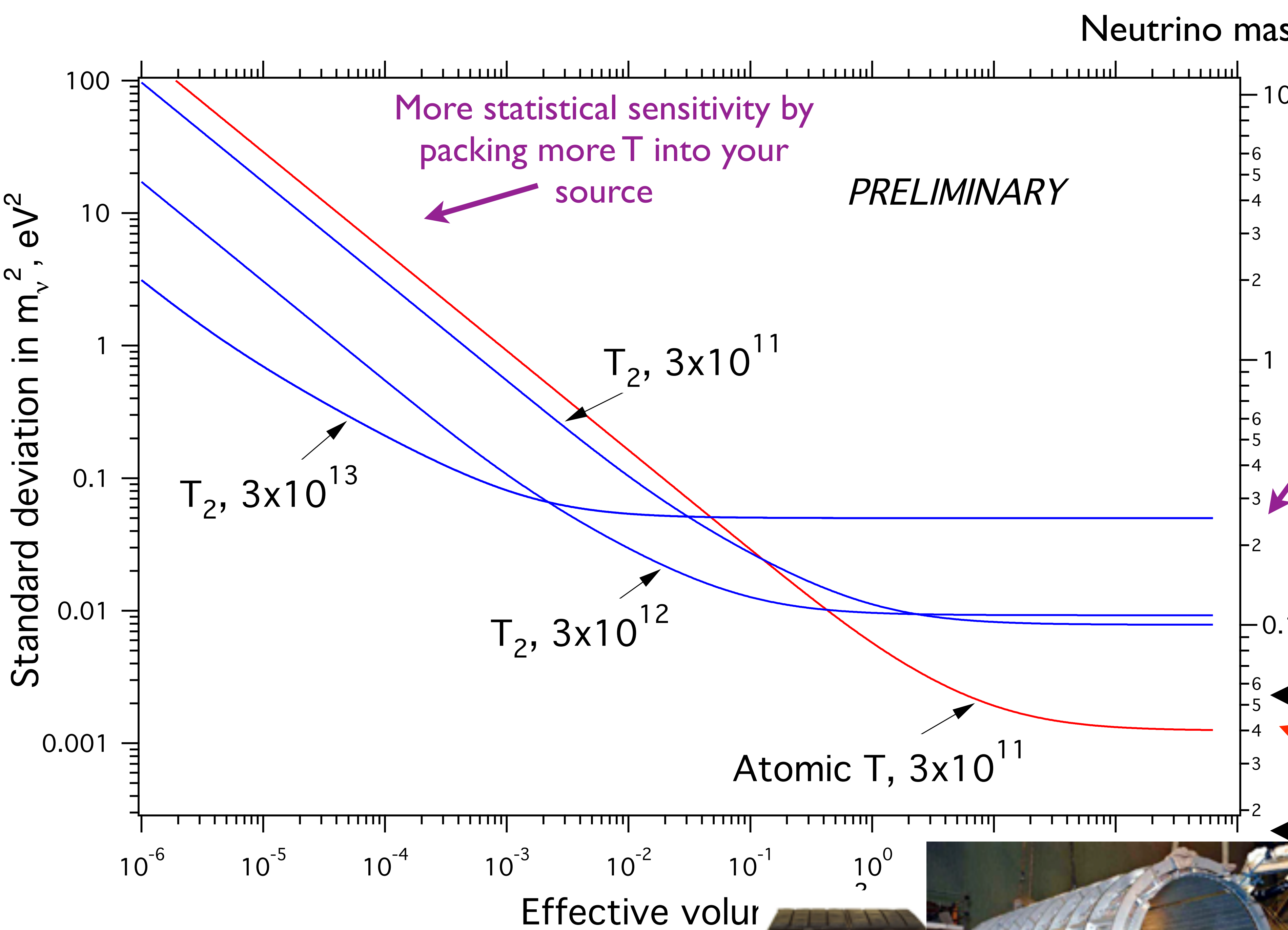

Details: B=1 Tesla, background = 1 μHz/eV, livetime 1y, angular acceptance 1 ster,
pressure broadening known to 1%, field broadening < $10^{-7}$

# Recent sensitivity estimates




Details: B=1 Tesla, background = 1 μHz/eV, livetime 1y, angular acceptance 1 ster, pressure broadening known to 1%, field broadening < $10^{-7}$


# Recent sensitivity estimates



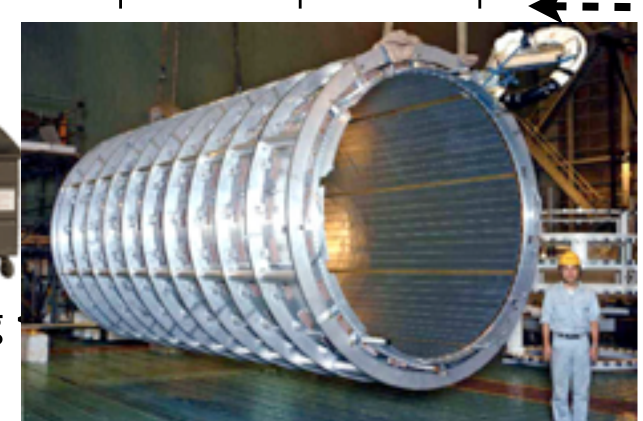

If source is too dense, limit is systematic error on linewidth (approx. 0.25 eV) accessible with 2 mCi, 1 liter

Molecular tritium final-state uncertainty (0.1 eV) ~20 mCi, 100 liter

inverted hierarchy

Atomic T experiment 200 mCi, 5 m$^3$

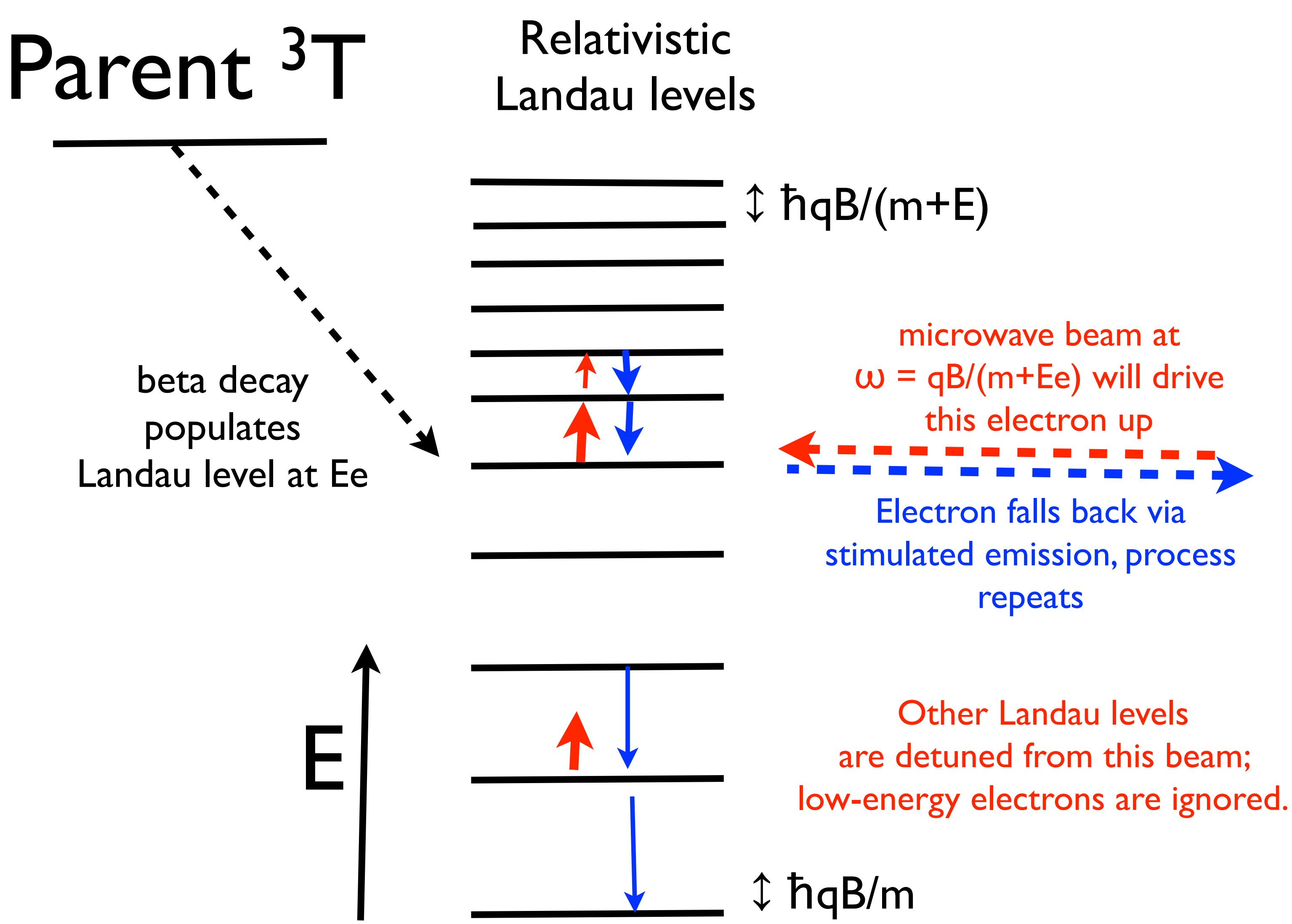
normal hierarchy

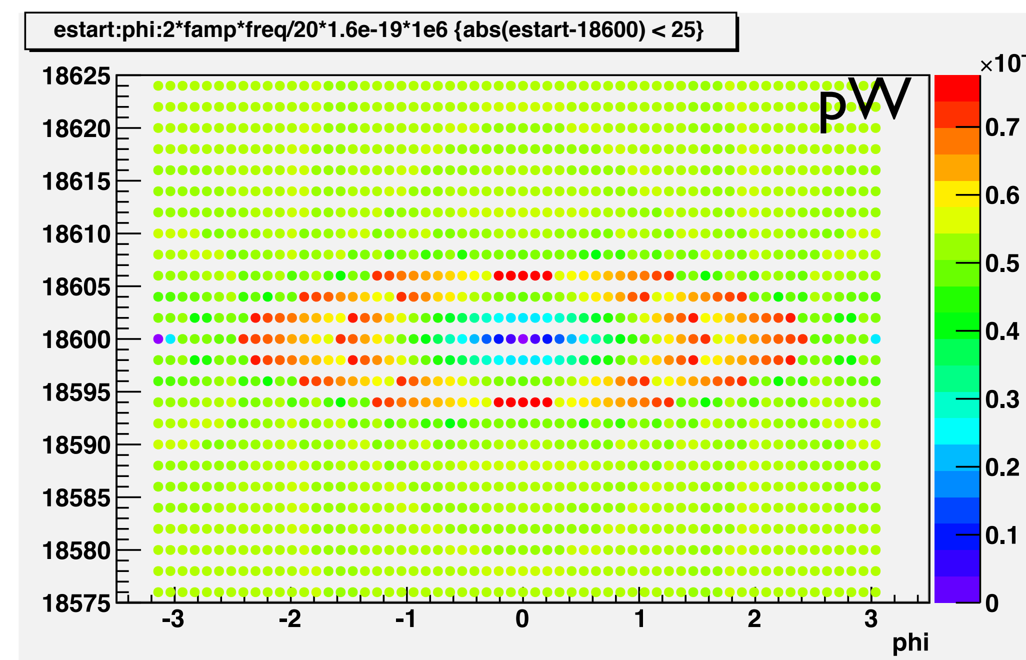
Details: B=1 Tesla, background = 1 μHz/eV, livetim
pressure broadening known to 1%, field broadening

# Upgrade: single-electron maser?

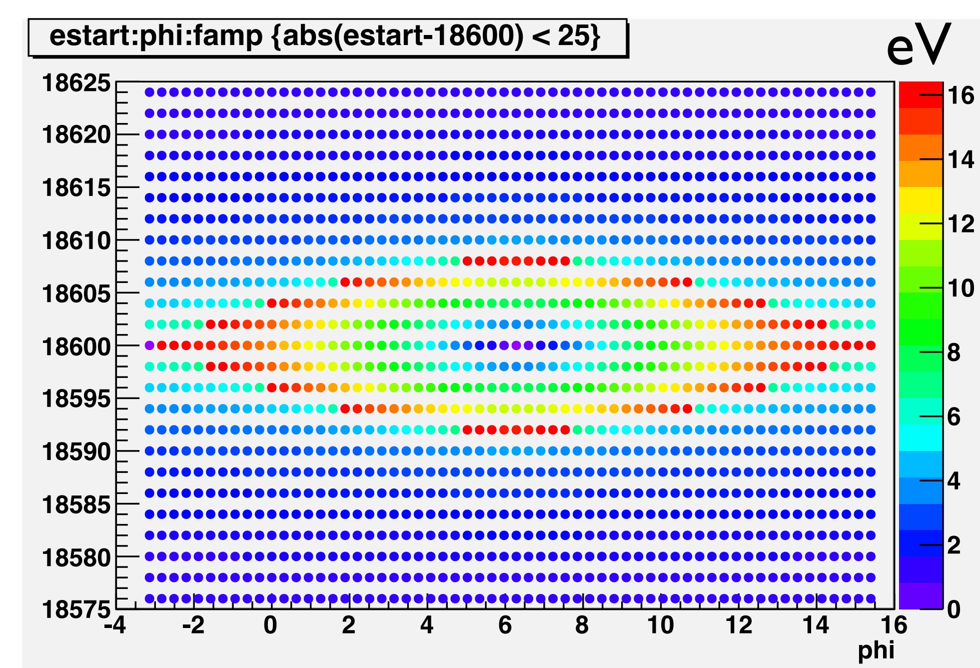
- A microwave probe has a stable (synchrotron) resonance with a cyclotron electron of the right frequency.
- Follow up each electron detection with a low-resolution, high-SNR “maser tag” for verification.




Single electron can absorb/emit large power from resonant probe beam ...

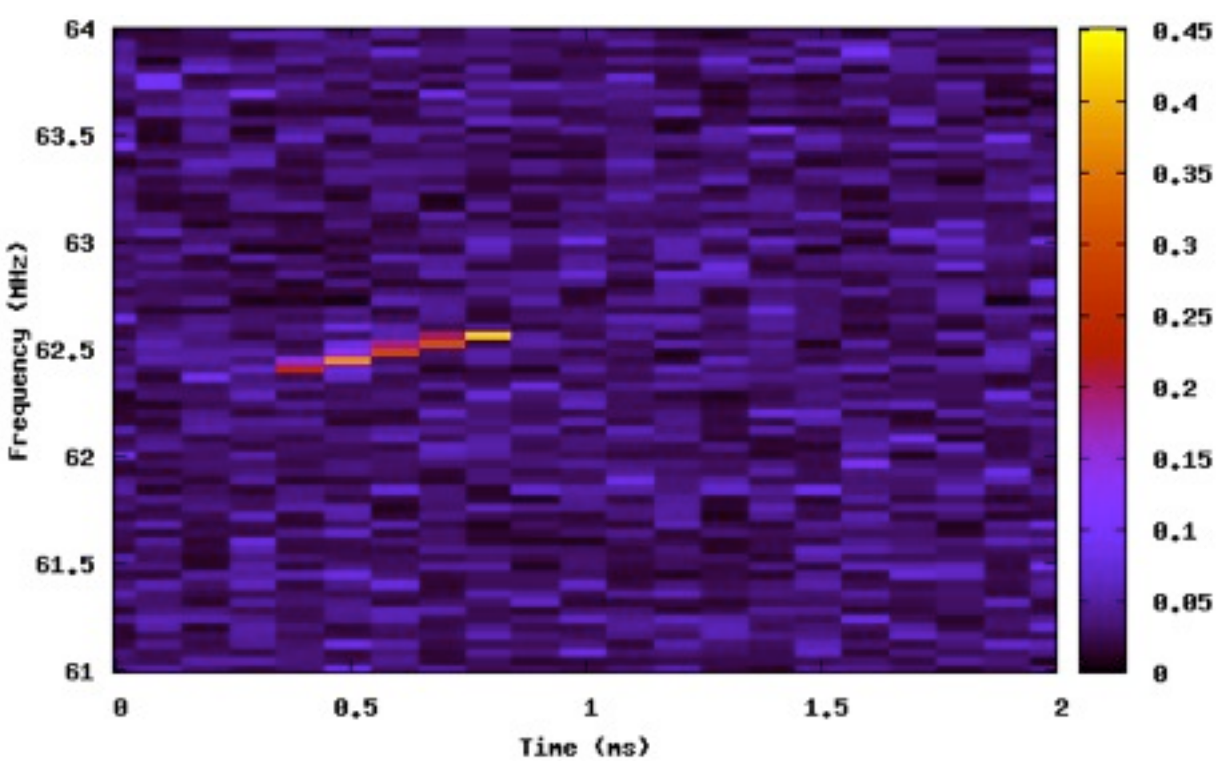



... but a strong probe beam makes a wide energy window



# What's next?

UC Santa Barbara:
B. LaRoque, B. Monreal
California Institute of Technology:
R. Patterson
Haystack Observatory, MIT:
S. Doelman, A. Rogers
Jefferson Laboratory:
M. Philips
Karlsruhe Institute of Technology:
T. Thuemmler
Massachusetts Institute of Technology:
J. Formaggio, D. Furse, N. Oblath
National Radio Astronomy Observatory:
R. Bradley
Pacific Northwest National Laboratory:
D. Asner, J. Fernandes, M. Jones, B. VanDevender
University of Washington:
P. Doe, J. Kofron, E. McBride, H. Robertson, L. Rosenberg, G. Rybka




- UW prototype will run again this year
  - First electron detection
  - maybe some physics spectra
  - (no tritium any time soon)
- UCSB cyclotron maser experiments under construction
- Preparing to propose the 1-liter, eV-scale experiment
- Read our Snowmass whitepaper!
- Looking at other physics (neutron decay, fundamental constants)